$WW+WZ$ in $\ell\nu$ +jets

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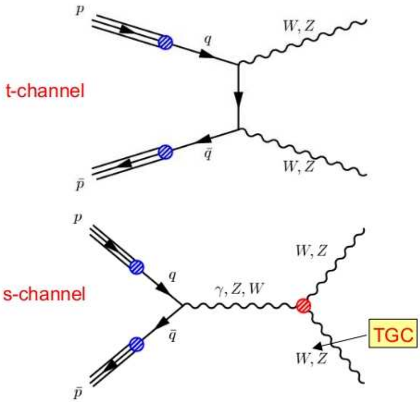
Seminar

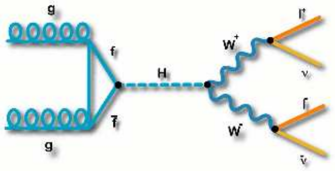
10/26/2010

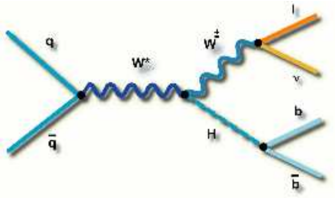
Why Diboson?



- Studies of electroweak (EW) vector boson production are an important aspect of the Tevatron physics program.
- Potential for new physics is manifest in:
  - Precision measurements of mass and EW parameters
  - Relationships between the masses of the W and Z
  - Increased cross sections or changes in kinematics
- Sensitive to new physics signatures

- $H \to WW$ is the dominant decay mode for a high mass Higgs ($m_H > 135$ GeV/c^2)
    - Drives current exclusion limits
    - Direct diboson production is the single most important background
    - Importan to understand
- $WH \to \ell\nu b\bar{b}$ is a promising search mode for low mass Higgs ($m_H < 135$ GeV/c^2)
    - Similar topology/final state to WW/WZ$\to \ell\nu q\bar{q}$
    - Similar challenges $\to$ S/B WH 1.2% WW/WZ 2.9%

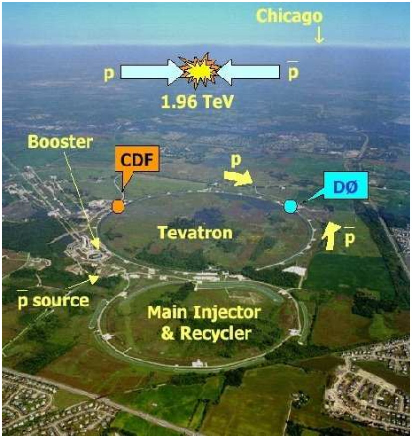


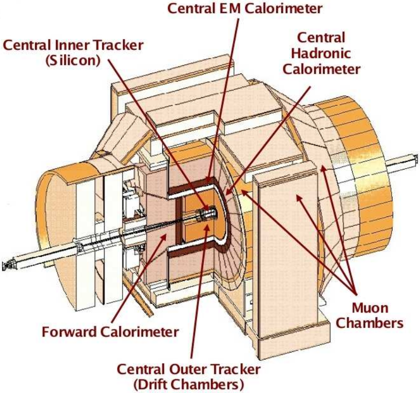


WW/WZ$\to \ell\nu q\bar{q}$ is a proving ground for Higgs search

CDF detector

- Proton-antiproton collision at $\sqrt{s} = 1.96$ TeV
- 36 bunches: crossing time = 396 ns
- Peak luminosity $4 \cdot 10^{32}$ cm^{-2} s^{-1}

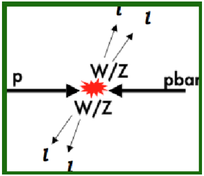


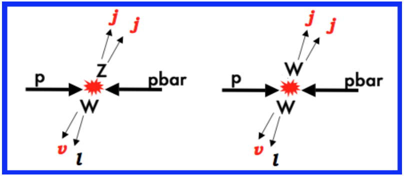


- About 8 fb^{-1} on tape
- This analysis uses 4.3 fb^{-1}

Diboson final states

- WW, WZ and ZZ production has already been seen in leptonic final states:
  - Clean Yields but low BR
- Semi-leptonic modes suffer from large background:
  - WW, WZ, ZZ seen in $\not{E}_T$ + jets mode
- Looking at $\ell\nu$ + jets final state:

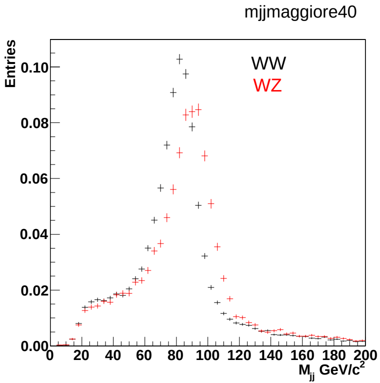


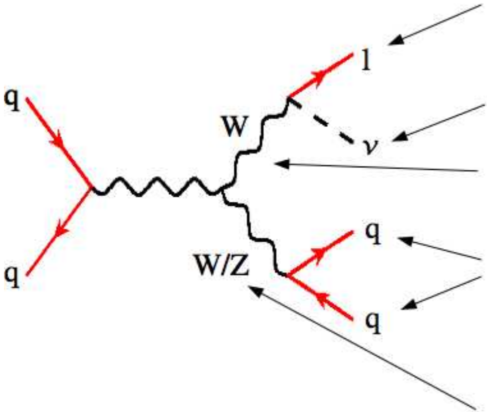


Signal: $\sigma(p\bar{p} \to WW/WZ) = 15.9 \pm 0.9$ pb
Background: $\sigma(p\bar{p} \to W + jets) = 2066$ pb
$\sigma(p\bar{p} \to Z + jets) = 187$ pb

WW vs WZ

- We treat events from WW and WZ as indistinguishable signals
  - Largely due to insufficient dijet mass resolution: 10 GeV difference in mass
- Consider the relative selection efficiency for WW vs WZ:
  - WW (WZ)$\rightarrow \ell\nu jj$ branching fraction: $\sim$ 28.5 (14.2)%
  - WW (WZ)$\rightarrow \ell\nu jj$ $\sigma \cdot BR$: $\sim$ 3.5 (0.5) pb

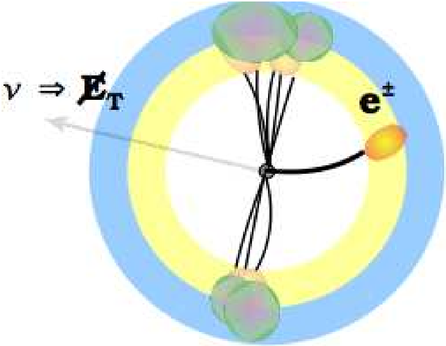


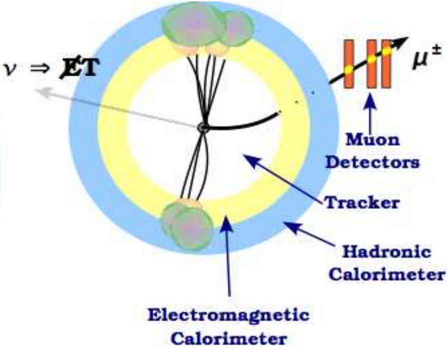


- Trigger on the charged lepton.
- Require missing transverse energy.
- Get a sample of inclusive W.
- Look for at least two jets and form the invariant mass.
- Fit the expected W/Z and background dijet mass shape to data to extract the Di-boson fraction.

$W \to \ell\nu$

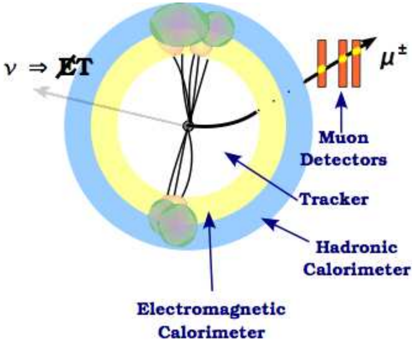
- One lepton (electron or muon) with $E_T/p_T > 20$ GeV and $|\eta| < 1.2$.
- Undetected neutrino manifests as an imbalance in transverse momentum: "missing" transverse energy ($\not{E}_T > 25$ GeV)
- To reduce multijet backgrounds, we require $M_T^W >$ 30 GeV.





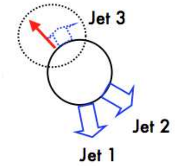
$W/Z \to q\bar{q}$

- Quark jets arising from W/Z$\to$ $q\bar{q}$ decays are very energetic and relatively central
- Cluster energy in cones of $\Delta R <$ 0.4
- Calorimeter signature must be inconsistent with electron signatures
- $E_T > 20$ GeV and $|\eta| < 2.4$



Backgrounds

- $W \to \ell\nu$ + jets $(l = e, \mu, \tau)$:
    - same signature as signal with a much higher cross section.
    - Almost 80% of the sample
    - Shape is taken from Alpgen MC
- $Z \to ll$ + jets $(l = e, \mu, \tau)$:
    - where one of the two leptons escapes detection and produces $\not{E}_T$
    - shape taken from Alpgen MC.
- $t\bar{t}$ + single top: shape taken from Pythia MC.
- QCD Multijet :
    - e.g a three-jet event in which one jet passes all lepton cuts and, simultaneously, the energies are so badly measured that a large $\not{E}_T$ is reported.

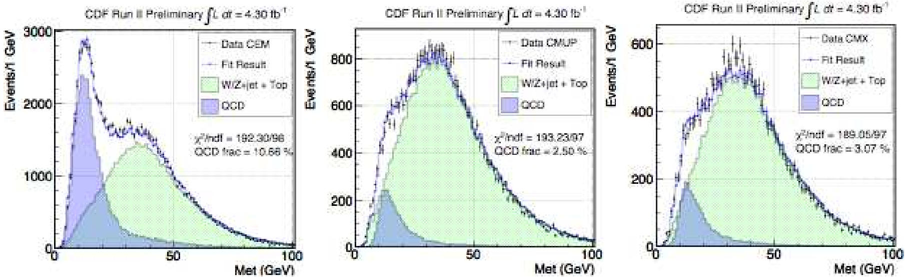


QCD estimation

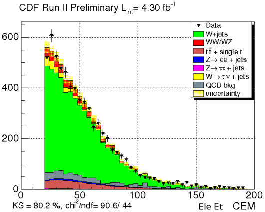
- "AntiElectrons":
  - Some non-kinematic cuts for the electron (EHAD/EM ...) are used to reject fake electrons.
  - Model is constructed of events which fail at least two of the non-kinematic cuts but pass all the kinematic cuts of the electron.
- "Non isolated muons":
  - Using non-isolated events, events which pass all selection criteria except the requirement of lepton isolation.
  - Based on the rationale that non-isolated events are typically leptons contained in jets, and jets that contain energetic leptons are more likely to pass lepton identification cuts.

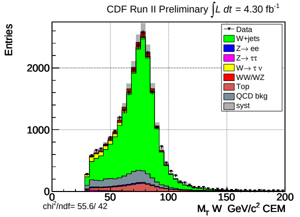
QCD estimation

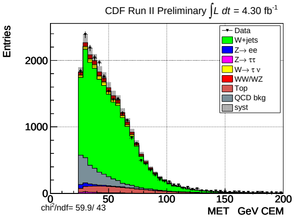
- QCD multi-jet events do not have neutrinos so met distribution is completely different from W+jets
- Fit the $\not{E}_T$ distribution on data
- Extract the fraction of qcd and knowing all the others contributions can extract also the W+jets normalization.

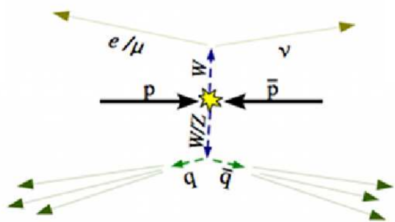


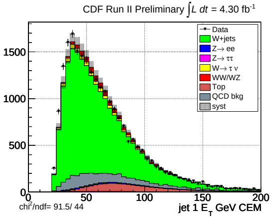
Event selection

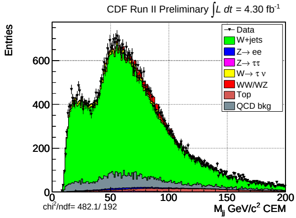


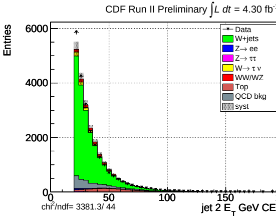


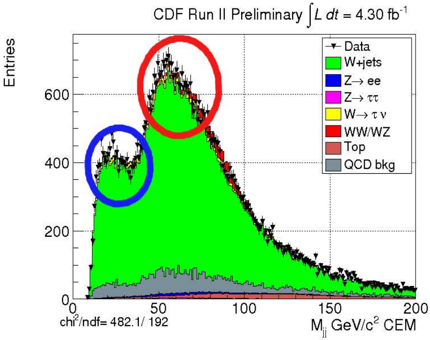


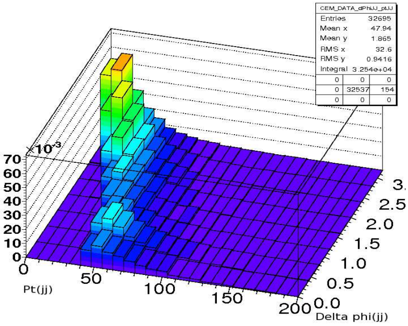






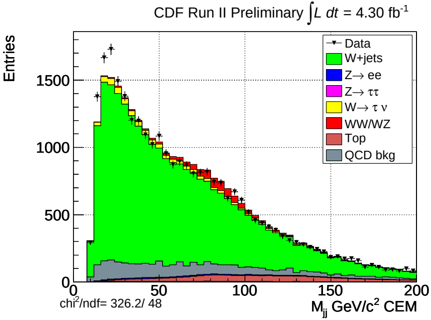


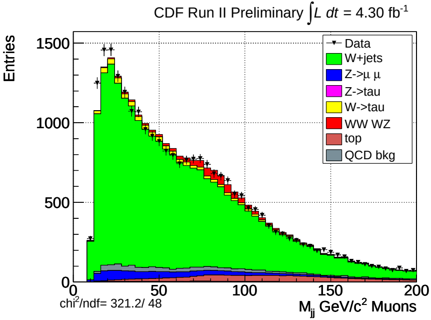




- The E_T threshold on the jets gives rise to two peaks:
  - At $m_{jj} \sim$ 20 GeV for almost collinear jets with $\Delta\phi \sim 0.5$ where the invariant mass is minimum and the combined $P_{T,jj}$ is maximum
  - The second one is at m_{jj} ∼40 GeV, for back to back jets ($\Delta\phi \sim \pi$), where the invariant mass is maximum.
- Decide to cut at $P_{T,jj} > 40$ GeV/c → loss of ∼ 40 % of the signal

"Old style analysis"





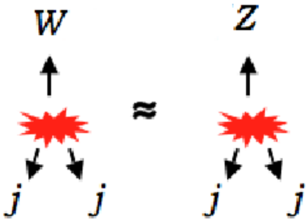
- Want to fit the m_{jj} distribution
- Need to be sure of the shape of every component

Checking the background shapes

- W+jets
- QCD backgrounds

Checking W+jets shape

- Use Z+jets data to check ewk shape
- Basid Idea : Similar kinematics
- Kinematics of Z+jets not necessarily the same of W +jets → need to account for this



- Method:

$$Z + jet(data) \approx \frac{Z + jets(MC)}{W + jets(MC)} \cdot W + jets(data)$$

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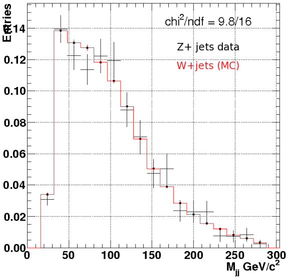

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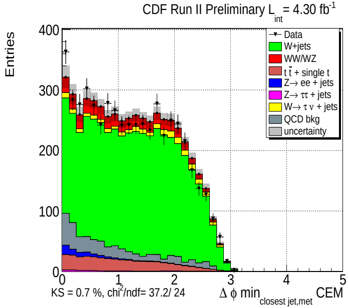
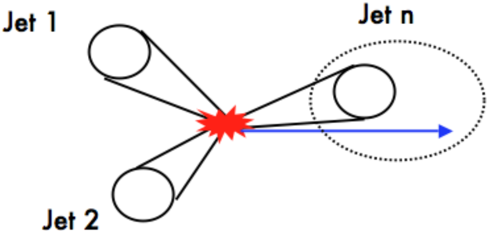
Checking the QCD shape I

- QCD $\rightarrow$ less understood background
- Need independent ways of checking the shape and rate
- Variable sensitive to qcd shape is $\Delta\phi(\not{E}_T$closest jet)

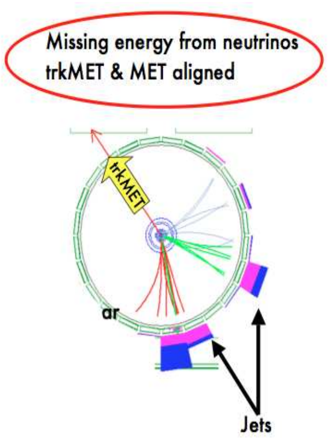




Mis-measured jet tends to align with MET
→Δφ should help rejection

Checking the QCD II

- $\not{E}_T$ is normally calculated at calorimeter level
- Can also estimate it using tracks
- True $\not{E}_T$: $\Delta\phi(\not{E}_T, \text{trkmet})$ small
- Fake $\not{E}_T$: $\Delta\phi(\not{E}_T \text{trkmet})$ large (it could point anywhere)



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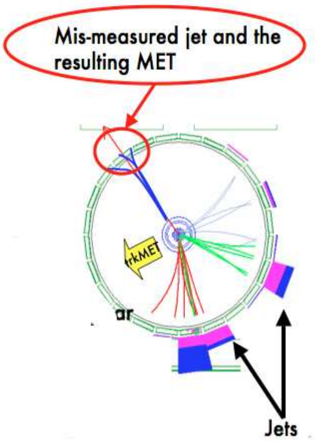

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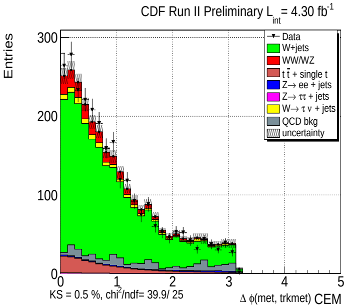
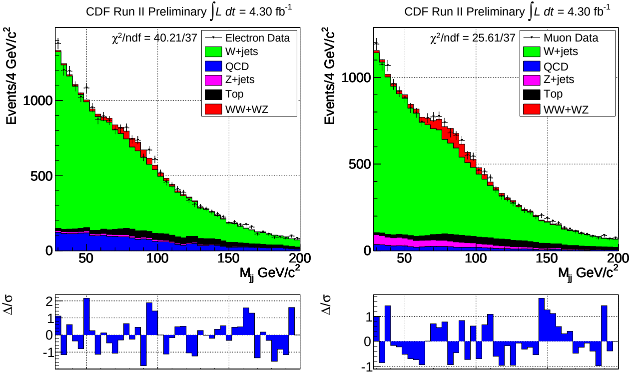


Fit to M_{jj} distribution

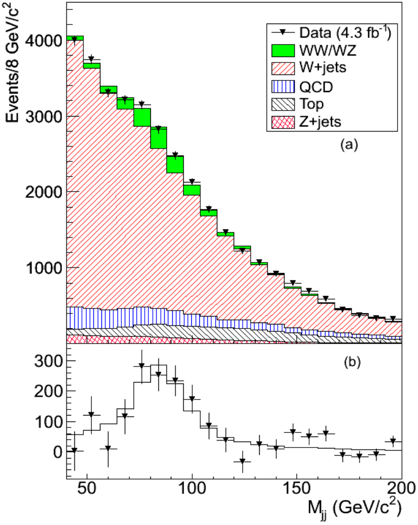
- Binned fit to the mjj shape taking as templates the histograms:
  1. W+jet $\longrightarrow$ completely free in the fit
  2. SIGNAL (WW and WZ)
  3. QCD $\longrightarrow$ gaussian constraint to the value found in the $\not{E}_T$ fit with 25% width.
  4. Top+single top : constrained to the measured cross section
  5. Z+jet: constrained to the measured cross section



Systematic summary

- Consider two classes of systematics:
  1. systematics affecting signal extraction
  2. systematics affecting signal cross-section
- Dominant Systematic for signal extraction:
  1. Shape of W+jets: evaluated changing the Q^2 of the MonteCarlo generator (6%).
  2. Jet energy scale: evaluated varying the Jet energy scale up and down of 1 σ (6%).
  3. QCD Shape: (4%).
- Dominant Systematic for signal cross-section:
  1. Luminosity 6%
  2. ISR/FSR 2%

Fit to data and results

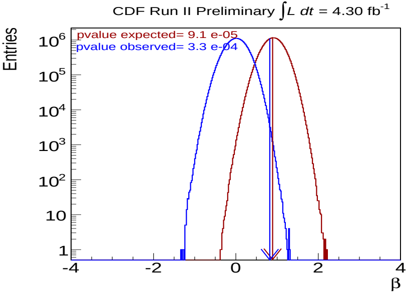


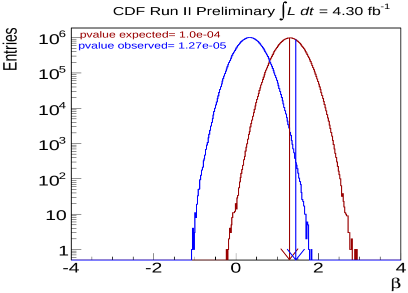
With $1582 \pm 275(\text{stat.}) \pm 107(\text{syst.})$ events this is the first observation (5.24σ) of $WW + WZ \to \ell\nu +$ jets. The resulting x-sec is

$$\sigma(WW+WZ) = 18.1 \pm 3.3(\text{stat.}) \pm 2.5(\text{sy}$$

that is in agreement with SM expectation $(15 \pm 0.9$ pb).

Significance estimation

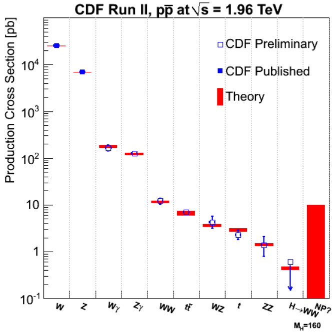




- Generate one toy for each combination of the N_{syst} i.e. in each sample some of the systematic are varied.
- For each sample evaluate how many times the toy results exceeds the value observed in data and choose the worst
- The combined p-value is $8.56 * 10^{-08}$
- 5.24 σ found where 5.09σ was expected

Conclusion

- Measured the cross section of WW/WZ $\rightarrow l\nu$ +jets
  - Opens the way to diboson studies with jets
- PRL published on march 2010: Phys. Rev. Lett. 104, 101801 (2010)
- Webpage for the update

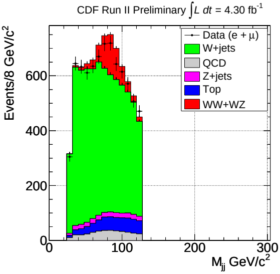


- Work in progress:
  1. Tagged analysis for $WZ \rightarrow l\nu+$ bjets ($\sigma = 0.12$ pb)
  2. Model independent search for di-jet resonances associated with a W

Backup

Search for a di-jet resonance

- Using the same final state to look for resonances in the di-jet mass spectrum
- Since we are looking at heavier resonances moved the E_T cut to 30 GeV



General strategy for a bump hunt in the di-jet invariant mass:

- Mass search region: $120 < M_{jj} < 200$ GeV/c^2
- The only assumption is that the signal width is compatible with the experimental resolution: so the expected width is

$$\sigma_{resonance} = \sigma_W \sqrt{\frac{M_{jj}}{M_W}}$$

Fitting procedure

- Combined χ^2 fit to electrons and muons
- 6 templates:
  1. $W +$ jets (Free)
  2. QCD (constrained to its fraction with 25 % error)
  3. $Z +$ jets (constrained to the measured cross section)
  4. top & single top (constrained to the measured cross section)
  5. WW/WZ (constrained to the theoretical cross section)
  6. new resonance (gaussian with width related to the mass)
- Procedure:
  1. Fit the data without the resonance $\rightarrow$ evaluate χ^2
  2. Fit the data with the resonance $\rightarrow$ evaluate χ^2
  3. We add 3 degrees of freedom to the fit (mass, separate yields) so the $\Delta\chi^2$ should have the distribution of a χ^2 with 3 degrees of freedom.
  4. Verify the behaviour of the $\Delta\chi^2$ with toys with trial factor.